Through a Fuzzy CTL Logic for Modelling Urban Trajectories
A Framework for Modelling City Evolution from Past to Future

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Abstract: A city is by definition a relatively large town of a significant importance. It is a centre of population, commerce, culture, industry, etc. The city evolves over time and gets morphological, sociological, economic and political transformations. Geographic Information System (GIS) may be used in spatial analysis of both the current city and its evolution over time. Based on the past and the present of a city, we are interested in developing a methodology that goes from the spatiotemporal modelling of its evolution to its prediction in the future. The motivation behind this research is to create a tool for the decision support at the disposal of the town hall. This tool aims to help making future decisions about investments, transport networks, infrastructures, etc. In this paper, we propose a framework that allows defining the possible trajectories of the city following the spatial, temporal and functional dimensions. The definition of those trajectories will be attached to a reasoning based on logic according to modalities, time and the imperfect nature of the information (imprecision, uncertainty, etc.).

1 INTRODUCTION

Geographical Information System (GIS) could be viewed as a set of tools that allow gathering, handling, analysing and displaying the data from various sources (Burrough and McDonnell, 1998). These data are localized information that contributes to the space management. Spatial information is mainly used according to specific objectives. GIS has an important role in many fields, including history and urban planning, which involves them in all phases of data processing starting from the data collection and ending with the visualization of the built maps. Historians and geographers may study the history of cities using GIS for analysing them over long periods of time. In the urban planning field, GIS tools enhance urban planners' analytical, problem-solving and decision making capabilities.

Urban planning is a future-oriented activity mainly conditioned by the past and the present. Therefore, a natural way for modeling the city evolution is to exploit a logical framework based on the past of the city that allows modeling rules according to temporal links using modalities. Indeed, modal logic and/or temporal logic may help us for defining consistent processes over time. For instance, as in the previous example, the emergence of means of transport (roads, railways) has contributed very closely to the economic and urban development (construction, extensions of existing production sites) and to the sociological development (populating area, immigration).

To understand past, present and future of the city, it is important to identify the space in which its trajectory can be modeled. It is therefore, essential to establish a list of identified variables as a part of a city model and to generate a Cartesian logic in the interaction of these variables in space and time. Modalities and temporalities will give us the tools to define this trajectory.

In classic approaches, the imprecision of the stored information is not considered for modeling the urban trajectories. In deed, if the uncertainty of the scenario is studied for the prospective approach using probabilities, the modelling of the urban trajectories according to the vagueness of the initial data is still few studied.

In this paper, section 2 presents the nature of the studied object and of their possible evolution. Section 3 introduces the logics we would use.

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Section 4 proposes our framework. Section 5 is devoted a discussion and the conclusion.

2 URBAN TRAJECTORIES: OBJECTS AND EVOLUTIONS

Many researches focused on the modeling of the old cities' history. In particular, several studies targeted the development of a modeling approach to represent cities' shapes and their dynamic in the past time (Güting et al., 2000); (Pumain et al., 2006).

Urban objects are generally represented as the combination of three features (Peuquet, 2002):

- The function of the object (church, school, business, etc.),
- The space which is the location of the object,
- The time that corresponds to the existence of the object over time.

Thus, the trajectory of urban objects is determined by the different changes occurred in each one of the previous features. Over the time, the object can evolve by changing its function, its space or the both at once. In fact, it may only change its function and keep its space, change its space and keep its function or change both the space and the function at once.

It is completely obvious to say that the future of a city (urban area) is uncertain, and any scenario should be considered as it is. Nevertheless, we can study the different possible evolution according to the knowledge of the past and to the current rules for the change.

This knowledge is usually vague or imprecise. In fact, there are many possible sources of information: such as history studies, maps, city archives, current urban management laws and directives, etc. Then, consider the past time to retrace the shape of urban objects (city, agglomerations, urban areas, etc.) motivate as to wonder about the geographical dimensions, and the different changes that the city would have by evolving in the future.

Nevertheless, every stored data is subject to imprecision to each component of the information. Therefore, this component of the information should be taken into consideration. That is the main goal of our proposal. In order to present it, we should, firstly, introduce the different logics we will use.

3 LOGICS

Based on the past and the present of a city, we are interested in modelling its evolution in the future. To reach this objective, we have to define its spatiotemporal trajectory at an instant ti+1. In Figure 2, the city evolves in the space (x, y) during the period [ti, ti+1]: the points P1', P2' and P3' at ti+1 correspond to the evolution of respectively the points P1, P2 and P3 observed at the time ti. These future points are created based on expressions like "we think that P1 and P1' should always be matched", "it seems that P2 will be P2' ", "we know that P3 will always be P3", etc.

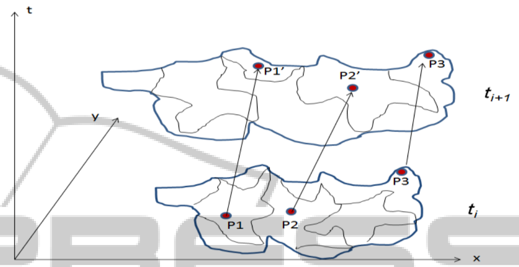

Figure 1: Illustration of two steps of a possible urban trajectory.

The elaboration of this trajectory requires the use of a logic offering ways to reason about expressions qualified in terms of time called also time modalities such as "it has been the case that p", "it has always been the case that p", "it will always be the case that p", etc.

3.1 Temporal Logic

Classical logic has a static nature that does not allow handling the concept of properties changing over time. Temporal logics are consequently, obtained by extending classical logics with temporal operators like always, all, some, until and next to express the evolution of a system over time.

They associate a truth value to a sequence of states representing the evolution of a system. The concept of truth in the temporal logic depends on the world evolution. It means that a proposition may be false at some time and becomes later true. This concept may be used to represent the acquired knowledge. These logics are defined on a set P of atomic propositions called also proposition variables. These atomic propositions are combined through a number of logical connectors, including the classic connectors (and, or, not, etc) and other operators called modalities.

Linear logics focus on the executions of the system without taking into consideration the interweaving of the different possible futures at a given point during the execution. In our approach, we will focus on CTL (Clarke et al., 1986), which has a representation in the form as a tree of possible executions. CTL offers the possibility to have several solutions over time and to model trajectories due to the branching aspect.

3.2 Modal Logic

In addition to the temporal logic, the elaboration of the trajectory requires also the use of a modal logic to express the possibility, prohibition, doubt, etc. about a logical proposition (*c.f.* Chellas (1980)). Modal logic is similar to traditional logic with the additions of modalities of possibility ("may be p", "it is possible that p") and modalities of the necessity ("necessarily p", "it is necessary that p"). In addition to the alethic modalities which are the modalities of necessity and possibility, modal logic handles also the modalities of the impossibility ("it is impossible that p"), the modalities of the belief ("we believe that p"), the modalities of the knowledge ("it is known that p") and the deontic modalities such as (" it is obligatory that p"," it is allowed that p").

3.3 Fuzzy Logic

The fuzzy logic (c.f. Dubois and Prade (2000)) offers the ability to deal with the vagueness through the representation of each concept by a fuzzy set. A fuzzy set characterized a concept through its possible domain values using a membership function taking values in [0,1]: 0 the confidence in the domain value for the concept is null, 1 the domain value is possible, and, in between, the greater the degree, the higher the confidence. On those sets, some operators such as AND, OR, NOT, etc. have been introduced in the literature. Using the three previous logics, we propose a framework that allows dealing with soft urban trajectories.

4 OUR FRAMEWORK

In our context, which is the urban objects' evolution modelling, it has to consider three parameters: time, space and function of the object (school, business, etc.). The construction of this trajectory will provide a global view of the various changes that the city will undergo. It also enables to predict its functional and spatial mutations. It is thus possible to answer questions like "How such a place will evolve?" "What will be the function of a given place at a particular time?" etc.

4.1 Fuzzy Object

This work is based on a fuzzy representation introducing various degrees of membership of an object to the time, to its function, and to the space as mentioned previously. Therefore, for each object o_l, our system may return a triplet of fuzzy sets: $<FTime_{ol}, FSpace_{ol}, FFunction_{ol}>$ with respectively the membership functions $<fTime_{ol}, fSpace_{ol}, fFunction_{ol}>$.

At a state *m*, one may evaluate the confidence in the possible presence of the object, called likelihood coefficient LK_m with the timestamp t_i, function F_k, the shape (geometry) S_j using the Zadeh t-norm:

$$LKm = \min(fTimeoj(ti), fFunctionoj(Fk), fSpaceoj(Sj)) \quad (1)$$

4.2 Soft Urban Trajectories

In our context, in place of classic triplet, we have triplet of fuzzy sets. Therefore for each object o_l, we may obtain at each ti a set of triplet $<t_i, S_j, F_k>$ from the domain values $<FTime_{ol}, FSpace_{ol}, FFunction_{ol}>$. Each triplet may represent a possible state *m* of the object. We can, thus, compute for each state *m* the likelihood coefficient LK_m. Thus each state of the model will be described by the quad <time, space, function, likelihood coefficient>, *i.e.* $<t_i, S_j, F_k, LK_m>$.

We have valued hypotheses of object presence over time. Therefore, the use of temporal logic is important in order to obtain the possible object mutations and the possible city model evolution. The main goal is to compute also a confidence index we may have in the global evolution model.

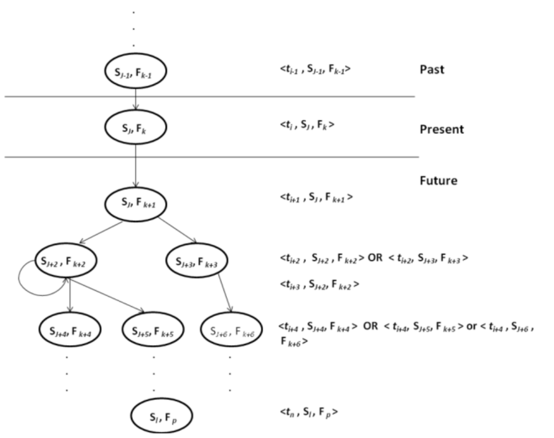

Figure 2: K transitions of an urban object over time with likelihood coefficient.

Figure 2 illustrates an example of the different possible transitions of an urban object from the instant t_{i+1} to t_n. At the instant t_{i+1}, the likelihood coefficient LK_m is assigned to the first state which has the function F_{k+1} and which will take place at the space S_{j+1}. At the instant t_{i+2}, two possible transitions are derived from the previous state leading to two possible states. LK_{m+1} is assigned to the first state with the parameters $<t_{i+2}, S_{j+2}, F_{k+2}>$ and LK_{m+2} is assigned to the second state $<t_{i+2}, S_{j+3}, F_{k+3}>$, and so on.

4.3 New Operators for Reasoning in Our Framework

By proposing a modal temporal logic, we aim to define in space the points that form the trajectory of the city at an instant t_{i+1}. In order to deal with the previous aspect (modality, fuzziness), we define 3 thresholds: the α-mean, the α-min and the α-max of the set of confidence degree LK_m.

We propose 4 new modal operators that we will deal with in addition to the classic CTL operators. At t_i:

$$N: \exists <t_i, S_j, F_k, LK_m> \text{ such as } LK_m < \alpha\text{-mean} \quad (2)$$

$$P: \exists <t_i, S_j, F_k, LK_m> \text{ such as } LK_m \geq \alpha\text{-mean} \quad (3)$$

$$Z: \exists <t_i, S_j, F_k, LK_m> \text{ such as } LK_m = \alpha\text{-min} \quad (4)$$

$$T: \exists <t_i, S_j, F_k, LK_m> \text{ such as } LK_m \geq \alpha\text{-max} \quad (5)$$

N is true when it exists, at a time t_i, a state $<t_i, S_j, F_k, LK_m>$ where the confidence degree is lower than the minimum of the confidence degree. The evolution hypothesis $<t_i, S_j, F_k>$ is then rather non credible. If P is true, then the hypothesis is rather possible. When Z is true, the hypothesis is impossible. When T is true, $<t_i, S_j, F_k>$ is credible.

4.4 Model Checking

Then we may combine the CTL and our operators in order to define an axiomatic that will be checked using a model-checking in which we may obtain both a confidence index in the model and a conflict index (using spatial constraint and logic). We will adapt the model-checking (Clarke et al., 1986) during the analyzing step.

Figure 3 illustrates the operational principle of the model checker that will be developed for the city evolution verification. The urban object's model evolution will be verified based on a set of specifications. These specifications are in the form of rules formulated in the modal temporal logic and obtained through a learning process carried out on old maps and plans of the city. The application of the verification algorithm indicates if the model is safe or not safe. If the model is safe, the evolution hypothesis is, then non credible, possible or credible. The evolution hypothesis is returned with the confidence degree. If the model is not safe that means that the evolution hypothesis is impossible. The latter is returned with the confidence degree and an example of an unsafe usage.

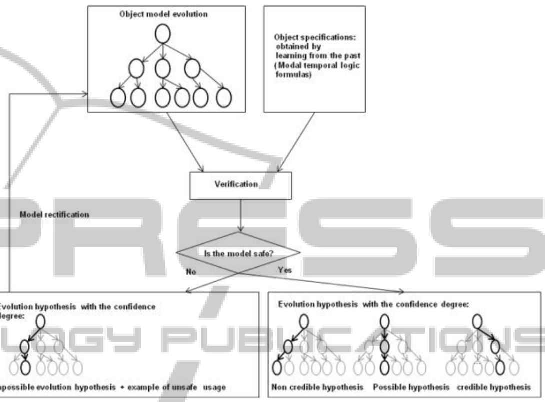

Figure 3: The model checking adapted to our framework.

5 CONCLUSIONS

In this paper, we introduce a new framework for modelling and reasoning on urban trajectories. Its main goal is to take into consideration the whole complexity of urban objects from their definition (vagueness, imprecision, space-time-function) to their exploitation (valued temporal and modal logic) through a unique and complete framework. In order to model our data and to produce new evolution scenarii, our approach uses modal, temporal, and fuzzy logics in a new kind of GIS.

REFERENCES

Burrough, P. A., McDonnell, R., 1998. *Principle of Geographical Information Systems*, Oxford University Press.

Chellas, B. F., 1980. *Modal logic, an introduction*, Cambridge University Press.

Clarke, E. M., Emerson, E. A., Sistla, A. P., 1986. Automatic Verification of Finite-State Concurrent Systems Using Temporal Logic Specifications, *ACM Transactions on Programming Languages and Systems*, Vol. 8(2), pp. 244–263.

Dubois, D., Prade, H., 2000. *Fundamentals of fuzzy sets.*

The Handbooks of Fuzzy Sets Series. Vol. 7. Springer.
Güttin , R. H., B'hlen, M. H., Erwing, M., Jensen, C. S., Lorentzos, N. A., Schneider, M., Vazirgiannis, M. 2000. A foundation for representing and quering moving objects. *ACM Transactions on Database System*, Vol 25(1), pp. 1–42.
Peuquet, D. J., 2002. *Representations of Space and Time*, The Guilford Press, N.Y.
Pumain, D., Bretagnolle, A. Glisse, B. 2006. Modeling the future of cities. ECCS'06, In *Proceedings of the European Conference of Complex systems*, Oxford, pp. 25–29.